PCT/AU03/01638

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PROVISIONAL SPECIFICATION FOR THE INVENTION ENTITLED:

IMPROVEMENTS IN TYRE PRESSURE AND TEMPERATURE MONITORING SYSTEMS

This invention is described in the following statement:-

The present invention relates to vehicle tyre pressure and temperature monitoring systems and, more particularly, to a two-wire communication channel between a vehicle's wheel mounted sensor means and chassis mounted receiving means.

There are two types of tyre pressure monitoring systems (TPMS) currently available which alert a vehicle's driver to abnormal tyre pressure conditions: direct measurement systems and indirect measurement systems. A direct measurement system measures tyre pressure directly with physical pressure sensors. Indirect measurement systems measure something other than actual tyre pressure, such as relative wheel angular velocities or axle to road height changes.

The class of direct measurement systems can be further categorized according to the means employed to provide power to the sensor and implement the communication channel between a vehicle's wheel mounted sensor means and chassis mounted receiving means. Notwithstanding power supply difficulties, just getting the signals off electrical sensors that are mounted inside the rotating wheels presents a serious problem. Prior art approaches typically involve either wheel mounted, battery powered radio frequency (RF) transmitter modules or chassis mounted electromagnetic induction (EMI) coils to energize the wheel's sensor and transmitter system.

Both approaches continue to suffer from system limitations and reliability problems.

Limitations of battery powered RF transmitter modules include:

- dependence on battery power sources inside the tyre (Once batteries are depleted, operation is compromised and replacement is costly);
- in order to conserve battery power, continuous monitoring is not possible, (Transmission of sensed information takes place only when

a pressure activation floor is passed (non-deterministic transmission algorithm)); and

- difficulties identifying tyre positions after tyres undergo rotation schedules (Usually, tyre positions must be reprogrammed).

Reliability limitations of both RF and EMI based approaches include:

- cross-talk between other adjacent vehicles with active transmitters and receivers;
- the receiver's electronics being subject to deafening by spurious energy fields from external sources (e.g., television transmitters, garage door openers and CB radios etc.,); and
- being affected adversely by the influence of metallic vehicle parts on energy field density patterns in the vicinity of the receiver antennae.

The performance of these prior art approaches varies greatly between vehicle models because every vehicle model has a different geometry that may interfere adversely with energy field densities.

In contrast, the present invention is based on the direct measurement TPMS approach which employs a robust directly connected two-wire communication channel between wheel mounted sensors and chassis mounted receiver electronics. Importantly, this approach obviates the need for sensor batteries inside the tyre, can use the minimum number of physical conductors (two), is economical and has a highly predictable and reliable performance.

The object of the present invention is to provide an economical and highly reliable system to alert the driver of a vehicle to any abnormal pressures, temperatures, angular velocities and force vectors which may exist in any or all of the vehicle's tyres (including the spare tyre) under all driving or stationary conditions. The system is deterministic and is not

affected by tyre replacement, tyre rotations, or deafening of the receiver electronics by radio frequency interference.

The present invention is directed to a system that provides power to wheel mounted sensor means so that they perform measurement of tyre pressure, temperature, angular velocity and force vector data. The system provides the means for the subsequent transmission of this data to chassis mounted receiving means and display subsystems. Normal and abnormal operating pressure and temperature information, for example, of a vehicle's pneumatic tyres are then available to a vehicle's driver.

In one form of the invention, there is provided a vehicle tyre data monitoring system comprising a wheel mounted sensor means adapted to transmit one or more of pressure, temperature, angular velocity, and force vector data for a tyre as a digital serial datagram through a two-wire communication channel to a chassis mounted receiving means, the communication channel being adapted to simultaneously supply power to the sensor means and receive the data for processing and subsequent display to a user of the system.

Preferably, the sensor means comprises a three or more terminal sensor subsystem having at least separate ground, power and data connections which is converted to a two terminal sensor subsystem for transmitting the data across the communication channel to the receiving means, with a first terminal being for a ground connection and a second terminal being for a combined power and data connection.

It is preferred that the two-wire communication channel superimposes the transmission of the data on the power connection as a serial datagram that is received by the receiving means.

Also preferably, the datagram is decoded by the receiving means to provide decoded information that is made available to a microprocessor system for analysis and display of the tyre data to a user of the system.

In another form of the invention, there is provided a two-wire communication channel for a vehicle tyre data monitoring system, the channel continuously connecting a sensor means mounted on a wheel of the vehicle with a receiving means mounted on a chassis of the vehicle, and being adapted to transmit pressure, temperature, angular velocity and force vector data for a tyre as a digital serial datagram from the sensor means to the receiving means and to supply power from the receiving means to the sensor means, the supply of power being simultaneous with the transmission and reception of the data, wherein the communication channel includes a two wire rotational coupling means having a first part mounted on a rotatable axle and hub assembly for the wheel and a second part fixed with respect to the chassis.

In yet another form of the invention, there is provided a rotational coupling in a two-wire communication channel for a vehicle tyre data monitoring system, the rotational coupling comprising a first part mounted on a rotatable axle and hub assembly for a wheel of the vehicle, and a second part fixed with respect to a chassis of the vehicle, the first part and the second part being adapted to maintain electrical contact therebetween during rotation of the axle and hub assembly for the transmission of decodable data for the tyre from a sensor means mounted on the wheel to a receiving means mounted on the chassis.

In still yet another form of the invention, there is provided a vehicle wheel to hub electrical mating interconnection in a tyre data monitoring system for the transmission thereacross of pressure, temperature, angular velocity and force vector data for a tyre mounted on the wheel, the electrical mating interconnection comprising a first part mounted on the wheel and adapted to receive the data from a sensor means, and a second part mounted on the hub and adapted to mate with the first part when the wheel is mounted on the hub so as to allow the data to be transmitted from the first part to the second part, the second part being further adapted to transmit the data to a receiving means

mounted on a chassis of the vehicle for processing and subsequent display to a user of the system.

Preferably, the mating of the first part with the second part occurs automatically during the mounting of the wheel on the hub, and demating occurs automatically during dismounting of the wheel from the hub.

Receiver interface electronics in the chassis mounted receiving means extracts the power line's superimposed serial data. The receiving means may be in the form of a module, and a microprocessor system in the module analyses the recovered data for abnormal conditions. The receiving module preferably has further interface options that are suitable for connection to various known motor vehicle body electronics systems. These interface options include the Bosch Controller Area Network (CAN) bus, GM's LAN bus, RS232 serial port and "Tell Tale" warning light with audible alarm.

In order that the invention may be more readily understood and put into practical effect, reference will now be made to the accompanying drawings, in which:-

Fig. 1 is a diagram of a two-wire communication channel for a vehicle tyre data monitoring system according to a preferred form of the present invention,

Fig. 2 is a diagram showing signal waveforms referenced to Fig. 1,

Fig. 3 is a diagram showing a complete five channel system for monitoring five tyres according to a preferred form of the present invention,

Fig. 4 is a diagram of a two-terminal sensor subsystem stud mounting encapsulation package used in a preferred form of the present invention,

Fig. 5 is a diagram of a tyre valve receptacle insulated electrode used to connect a sensor to the external face of the tyre rim in a preferred form of the invention,

Fig. 6 is a diagram of a wheel to hub electrical mating system for stub axle (eg NSK, SKF) assemblies used in a preferred form of the invention,

Fig. 7 is a diagram of an alloy wheel rim showing a sensor mounting and an electrical connection to a wheel to hub electrical mating contact assembly in a preferred form of the invention,

Fig. 8 is a diagram of a steel wheel rim showing a sensor mounting and an electrical connection to a wheel to hub electrical mating contact assembly in a preferred form of the invention,

Fig. 9 is a diagram of a wheel to hub electrical mating system for a drive axle (eg GM) assembly in a preferred form of the invention, and

Fig. 10 is a diagram of a through shaft two-wire rotational coupling in a preferred form of the invention.

1. Sensor Subsystem Interface.

Industry standard three terminal (Ground, Power and Data) pressure sensor subsystems are available which have a digital asynchronous serial data transmission output. They have a recommended power supply of between 2.5 and 3.6 Volts, a current consumption of typically 12 micro Amps, and operate over a temperature range of - 40 to + 125 degrees Centigrade.

Fig. 1 shows a typical three-terminal sensor subsystem having connections of Ground, Power (3.3Volts) and Asynchronous Serial Data Output. Fig. 1 shows Power being supplied to the sensor subsystem via a low noise, low voltage drop out, zero capacitor type voltage regulator (Vin=3.9 - 5.0 Volts, Vout=3.3Volts) with specifications as follows:

Process:	CMOS
Maximum Input Voltage:	5.5 V
Output Voltage:	3.3 V
Drop out voltage @ 50 mA:	55 mV
Operating Current @ no-load:	85 μA
Operating Current @ 50 mA:	150 μA
Input Capacitor:	None
Output Capacitor:	None
Output noise @ 100 KHz:	30 μVrms
Accuracy:	2.0 %
Line Regulation:	0.1 %/V max
Load Regulation:	0.02 % max

The voltage input to the voltage regulator is supplied from an industry standard 4000 B series Complementary Metal Oxide Semiconductor (CMOS) logic gate's output stage. The input to the CMOS logic stage (Fig. 2, Waveform 1) is part of a microprocessor controlled system and functions as a signal which initiates or requests the beginning of a data measurement and transmission cycle. With reference to Fig. 2, a serial datagram transmission from the sensor subsystem (Waveform 4) commences after a nominal delay following application of power (Waveforms 2 and 3) from the CMOS logic gate. The sensor subsystem's output datagram is transmitted in asynchronous serial format with a voltage swing of between 0 and 3.3 Volts. This voltage swing is applied to the CMOS logic gate's output via a 3.9 Volt Zener diode having the following specifications:

Zener Voltage:	3.90 V
Maximum Zener Current:	5.00 mA
Maximum Power Dissipation:	500 mW
Tolerance:	5.00 %

Temperature Coefficient:	-2.50 mV per °C
Load Regulation:	0.02 % max
DV / dI / Ohm	90.00

When the transmitted datagram signal is at 0 Volts, the Zener diode will conduct and operate in its avalanche region where large changes in current produce only small changes in diode voltage. The amount of current which the CMOS output is capable of sourcing or sinking is limited by the channel impedance of its complementary pair output structure. This current will be the sum of the Zener current, the voltage regulator operational current (a maximum of 150 micro Amps) and the sensor subsystem's current (a maximum of 12 micro Amps). Under these load current conditions the Zener diode will regulate its load voltage to 3.9 Volts, with the Zener diode's power dissipation well within its rating of 500 milli Watts. It should also be noted that in general, the outputs of standard CMOS devices are robust and may be shorted to the supply rails at low operating voltages. MOS transistors have a negative temperature coefficient, which results in inherent burn-out/short circuit protection.

When the transmitted datagram signal is at 3.3 Volts, the Zener diode current will be negligible and the CMOS output will remain at 5.0 Volts. The superimposed data waveform is shown in Fig. 2 Waveform 2. Actual data swing of between 3.9 and 5.0 Volts is superimposed on the CMOS logic gate's output stage. Throughout the datagram transmission, the regulated voltage of 3.3 Volts is maintained to the sensor subsystem by the low voltage drop out (~55 milliVolts) regulator (waveform 3).

2. Receiver Electronics Interface

Fig. 1 shows a single power rail (+5 Volt) operational amplifier configured as a voltage comparator and follower with positive feedback. (R1=10K) The positive feedback provided by R1 ensures clean rapid

changes of state. The input signal is the power line's superimposed data signal previously described in waveform 2. The reference discrimination voltage level is selected to be 4.5 Volts, approximately midway between the superimposed data values of 3.9 and 5.0 Volts. At a 4.5 volt reference threshold, hysteresis of the operational amplifier and the RC characteristics of the transmission line have negligible effect on the mark space ratio of the recovered signal at the low frequency (typically 56Kbps) of the data being transmitted. The capacitor C1 = 0.01 micro Farad is connected directly across the input pins to produce a clean comparator output. The capacitor C2 = 0.01 micro Farad minimizes susceptibility to AC coupling. The operational amplifier's output signal is the recovered data shown in Fig. 2, waveform 5. This output is now available as a 0 to 5 Volt digital signal to a microprocessor subsystem for further processing and subsequent control of the other system interfaces (CAN bus, etc) of the receiver electronics module.

Fig. 3 shows a complete five channel system with receiver electronics monitoring four rotating tyres and a spare tyre.

3. Two-Wire Communication Channels

The two-wire communication channel described herein converts each three terminal (Ground, Power and Data) sensor subsystem to a two-terminal device requiring one connection to the receiver electronics ground reference and the other connection to facilitate a simultaneous power with superimposed data signal to the chassis mounted electronics interface. Standard semiconductor foundry processes may be applied to replace the discrete electronics of the two-terminal sensor subsystem with a single monolithic integrated circuit encapsulated within an industry standard package, such as TO-220 standard or a stud design as shown in Fig. 4.

When a TO-220 case is used to encapsulate the two-terminal sensor, its ground terminal is electrically connected to a suitable nut which is

welded to the wheel rim's inside surface at a position of minimum diameter and adjacent to the valve stem receptacle, as shown in Fig. 8. The power/data connection eyelet of the two-terminal sensor subsystem is electrically connected to the bottom of the internal brass ferrule of a rubber valve receptacle using an M4 threaded stainless steel cap screw, locking washer and cylindrical brass spacer, as shown in Fig. 5. The M4 cap screw has a 2mm diameter axial hole to allow for the passage of air during inflation and deflation procedures. According to this arrangement, the valve receptacle now has dual functions of valve and insulated electrical terminal. The valve's ferrule electrically connects the wheel's internal two-terminal sensor subsystem's power/data signal to the wheel's outward facing external environment. An electrical connection between the valve receptacle's external brass ferrule and a wheel to hub electrical mating system is facilitated as shown in Fig. 8. The electrical connection may be made using a single insulated wire or a flexible mylar insulated single track printed circuit applied directly to the wheel rim. Electrical ground connection between wheel rim and hub is achieved via the wheel rim's contact with the metal of the wheel studs and wheel nuts.

Alternately, when the stud design of Fig. 4 is used to encapsulate the two-terminal sensor, it is mounted on the inside of the wheel rim via a hole located at a position of minimum wheel rim diameter as shown in Fig. 7. According to this arrangement, the wheel's internal two-terminal sensor subsystem's power/data signal is made available to the wheel's inward facing external environment. An electrical connection between the stud's insulated Power / Data pin and a wheel to hub electrical mating system is facilitated as shown in Fig. 6. The electrical connection may be made using a single insulated wire or a flexible mylar insulated single conductor track printed circuit applied directly to the wheel rim. Electrical ground connection between wheel rim and hub is achieved via the wheel rim's contact with the metal of the wheel studs and wheel nuts.

The wheel to hub electrical mating system is shown in Fig. 6 (Stub Axle) and Fig. 9 (Driven Axle). It should be noted that there are different hub axle arrangements for motor vehicles and that, whilst this description is of an application to a particular arrangement, it may be applied to any arrangement. The mating system allows the wheels to be removed and replaced in the standard manner whilst simultaneously providing an automatic electrical connection for the sensor subsystem's ground and power/data connections.

The two-wire communication channels are further extended to operate through a vehicle's rotating wheel assemblies. This is accomplished via axial holes that form a pathway through the axles and lead to rotational couplings. Rotational couplings (which are symbolically depicted in Fig. 1) are mounted in available axle spaces as shown in Fig. 6 (Stub Axle) and Fig. 9 (Driven Axle). The function of the rotational couplings is to make two continuous electrical connections from points on a stationary chassis to points on rotating wheels. Electrical connections are for both ground reference and power, with the sensor subsystem's transmitted data signal being superimposed on the power line connection. Coupling rotation speeds vary from zero (stationary) through a slow creep to high revolutions per minute (e.g., 2000 RPM).

Rotational couplings may be based on electromagnetic induction (EMI) designs where changing magnetic flux in a driving coil induces current to flow in another coil in close proximity, or they may consist of electrodes in contact. The EMI implementation requires more complex additional electronics (DC to AC and AC to DC conversion with data encoding and decoding), and the simpler low maintenance electrode type, as shown in Fig. 10, is the preferred embodiment.

The successful use of electrode type rotational couplings to implement the two-wire communication channels described herein is preferably dependent on achieving:

(1) low ohmic contact resistance (less than 1 milli ohm);
(2) low electrical noise insertion;
(3) electrical isolation between circuits;
(4) low maintenance and high reliability at continuous operating speeds of up to 2000 rpm;
(5) compactness and the arrangement of their physical installation and connector wiring pathway; and
(6) low cost.

Preferred rotational couplings of the electrode type for use in this invention have the following specifications:

Conductors:	2
Voltage Range:	0 - 12 V DC
Current Rating:	10 mA
Power Rating:	120 mW
Maximum Frequency:	200 MHz
Contact Resistance:	$< 1 m\Omega$
Maximum RPM:	2000
Operating Temperature:	-25 to 125 °C
Rotational Torque:	75 gm-cm
Circuit separation	$> 25 M\Omega$

The rotational coupling's contact arrangements for noise sensitive data signals include: fully "wetted" electrodes connecting through a shielded mercury pool or low ohmic contact electrodes riding on slip rings coated with similar materials. Suitable contact materials include silver impregnated carbon, silver, palladium and gold alloys. Multiple contacts per connection can be used to keep electrical noise extremely low using the

contact materials indicated. Where mercury is used, it is kept to the absolute minimum required by the connector. The rotational couplings used are selected to be cost effective and to provide a long, highly reliable service life in the wheel area environment where water, dirt and both high and low temperatures are prevalent.

The use of a Cyclic Redundancy Checking (CRC) algorithm applied to the sensor subsystem's serial datagram further enhances the ability of the overall system to cope with any noise introduced into the communication channel.

3.1 Practical Considerations of "Single Wire Coupling with Chassis Ground" Versus "Two-Wire Coupling"

In order to achieve the most elegant yet reliable implementation for the communication channel, a two-wire coupling system is preferred over a single wire coupling which relies upon the continuity of chassis ground for the second connection. The reasons are as follows:

Motor vehicles have two types of axles: stub axles and live, or driven, axles. In each type of axle, greased bearings are employed. The bearings have an inner and an outer surface. In one arrangement, the outer bearing surface is fixed to the vehicle's chassis/suspension whilst the bearing's inner surface is fixed to the axle. An opposite arrangement has the outer bearing surface fixed to the axle whilst the bearing's inner surface is fixed to the vehicle's chassis/suspension.

When a wheel axle's ball bearings are rotating, the bearing's metallic components become separated by elastohydrodynamic films of lubricating grease. Whilst this is desired for lubrication, unfortunately typical bearing grease presents high electrical resistance which results in the wheel rim's ground connection being insulated from the chassis ground reference. Additionally, the electrical resistance of each wheel's suspension and axle

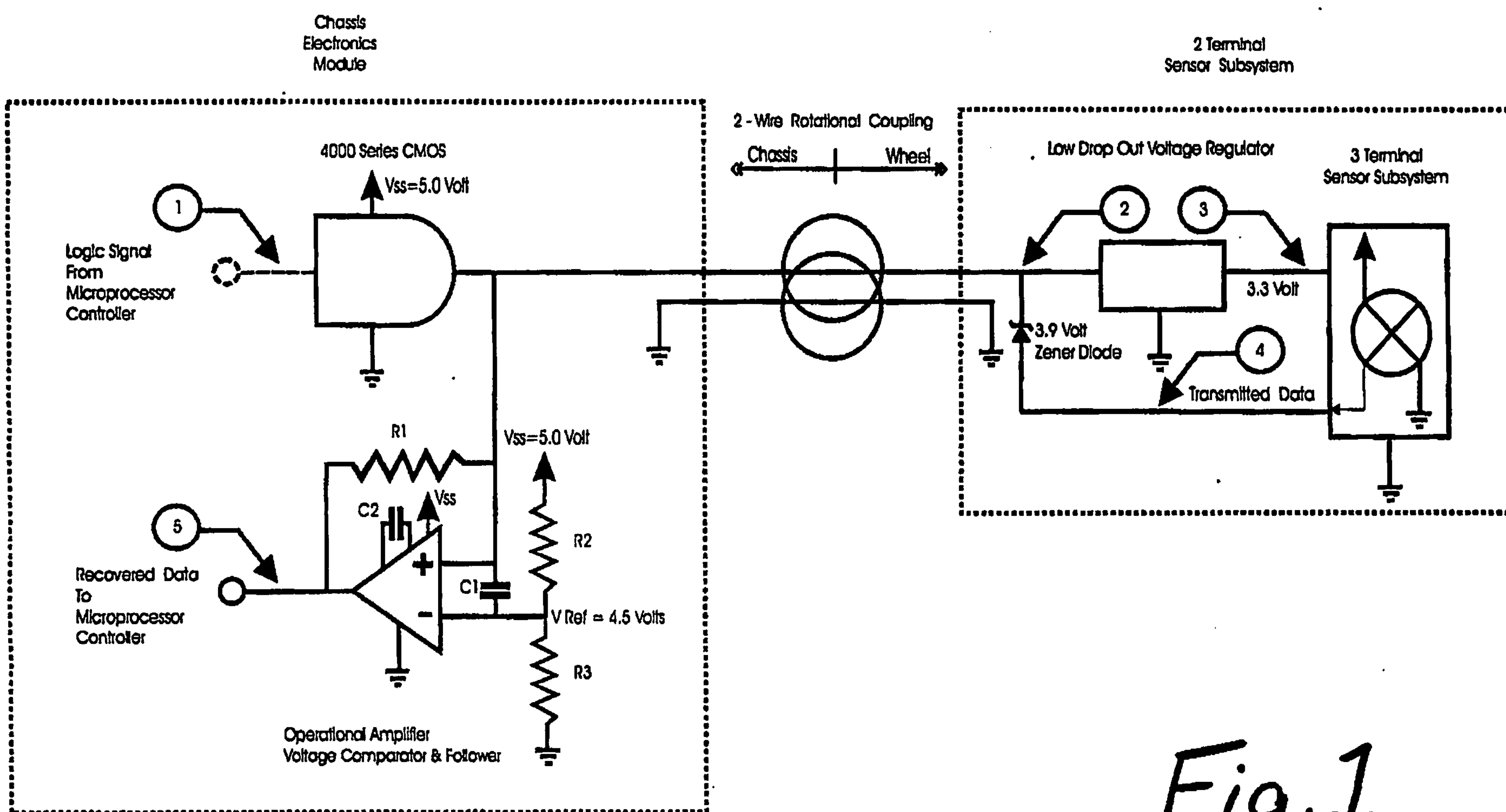
components (shock absorber mounts and transmission train ball bearing races) needs to be overcome in order to provide low resistance in the ground path. In most vehicles, the wheel's suspension mechanism employs rubber components, which also tend to insulate the wheel from the chassis.

Whilst the previously mentioned high resistance points may be corrected by the use of ground straps and suitable electrically conductive bearing grease, the preferred embodiment of this invention uses two-wire rotational couplings. Whilst stub axles have "end-of-shaft" mounting options for rotational couplings, driven axles typically require "through-shaft" mounting of rotational couplings. This invention uses both types of couplings and unique wiring pathways for each type of axle in order that the vehicle ground reference and signal connection to the sensor subsystems and receiver electronics module, used in the two-wire communication channel, can be strictly maintained.

It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as represented in the specific embodiments described and depicted herein, without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive.

Dated this 15 day of November 2002

Phillip Albert Cohen
Patent Attorneys for the Applicant
PETER MAXWELL & ASSOCIATES



Chassis Electronics Module
2 Terminal Sensor Subsystem
2 - Wire Rotational Coupling
Chassis
Wheel
4000 Series CMOS
Vss=5.0 Volt
1
Logic Signal From Microprocessor Controller
Low Drop Out Voltage Regulator
3 Terminal Sensor Subsystem
2
3
3.3 Volt
3.9 Volt Zener Diode
4
Transmitted Data
R1
Vss=5.0 Volt
C2
Vss
R2
5
Recovered Data To Microprocessor Controller
C1
V Ref = 4.5 Volts
R3
Operational Amplifier Voltage Comparator & Follower

Fig.1

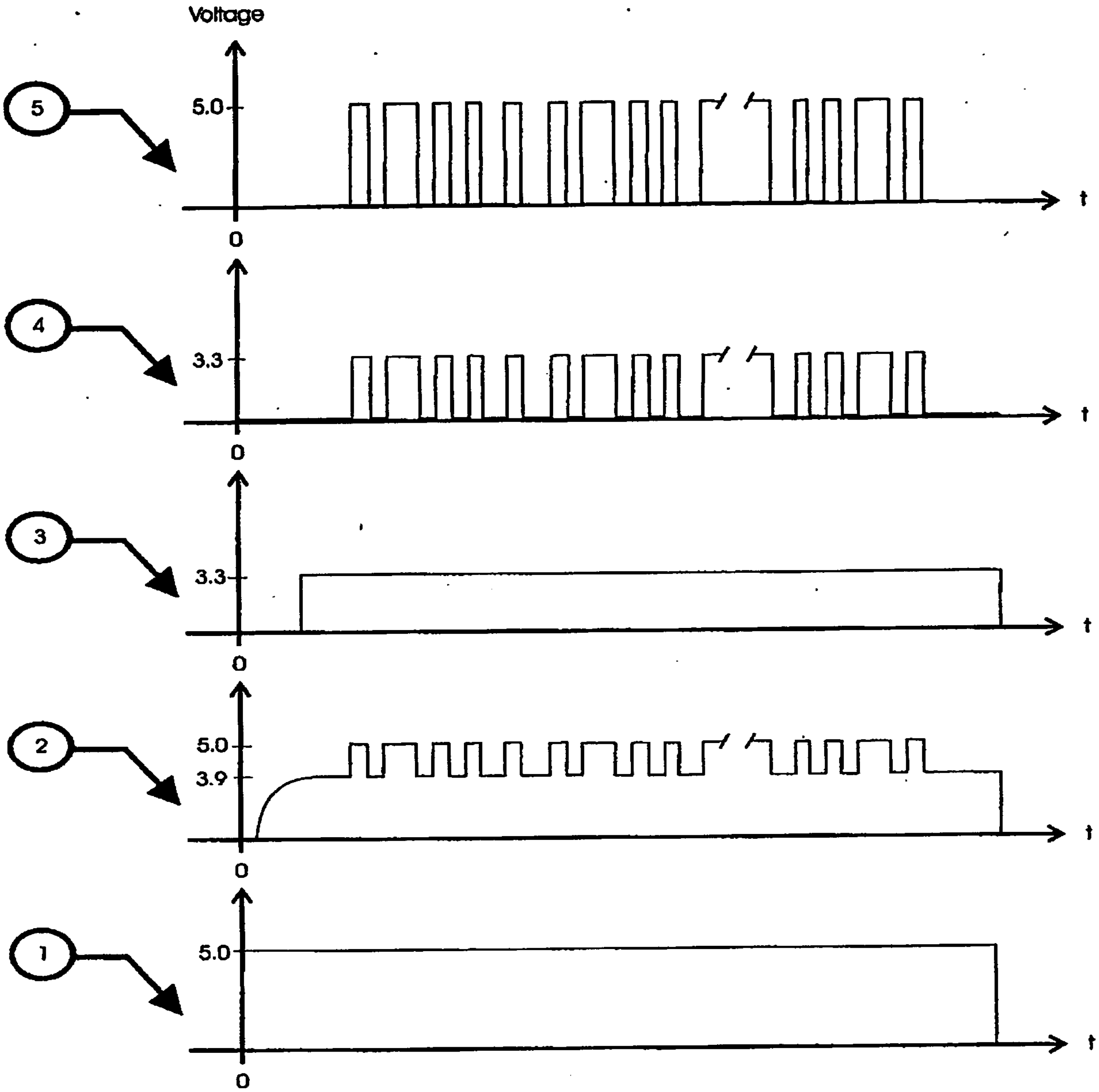


Fig. 2

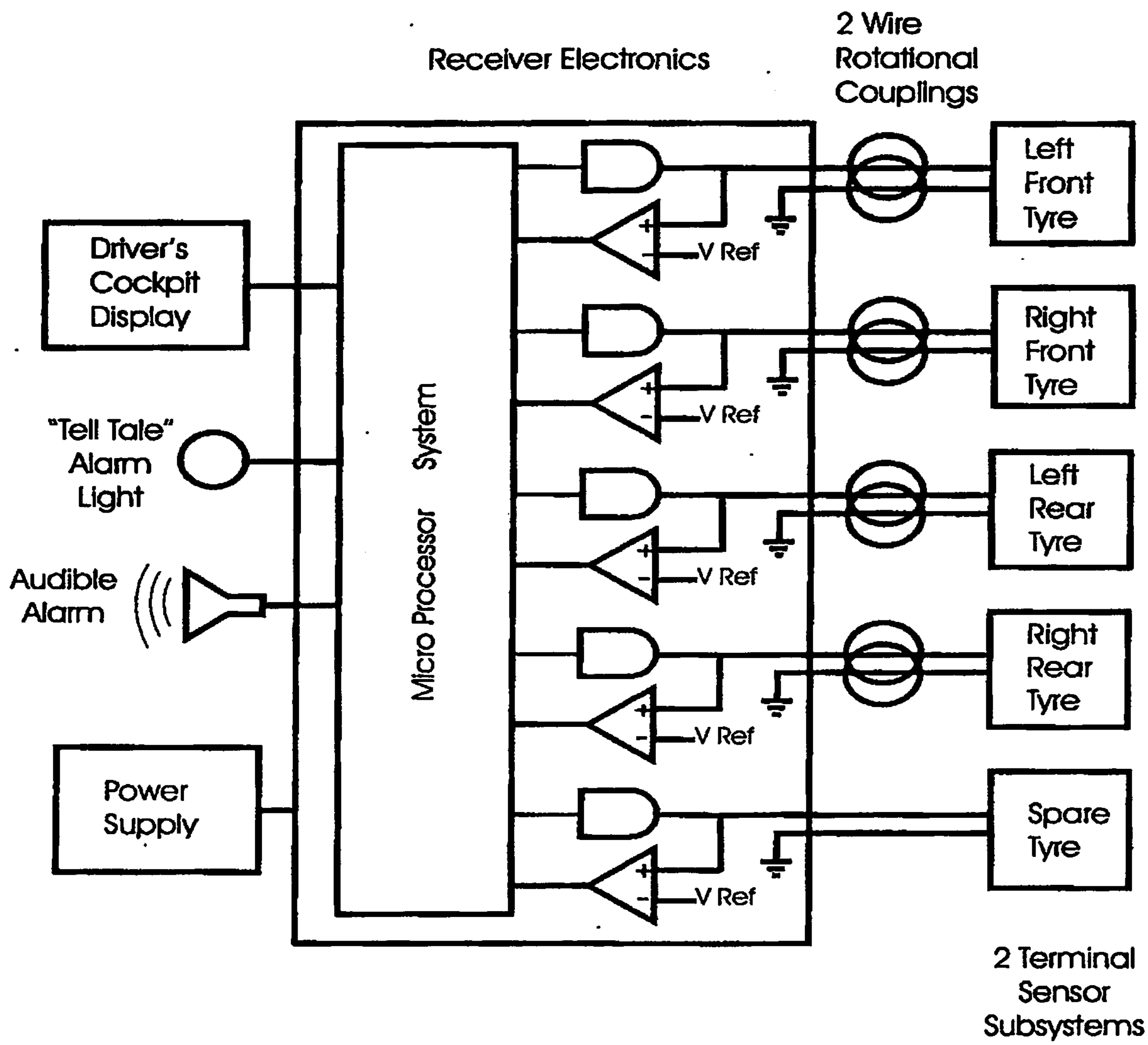

Receiver Electronics
2 Wire Rotational Couplings
Left Front Tyre
Right Front Tyre
Left Rear Tyre
Right Rear Tyre
Spare Tyre
Driver's Cockpit Display
"Tell Tale" Alarm Light
Audible Alarm
Power Supply
Micro Processor System
V Ref
V Ref
V Ref
V Ref
V Ref
2 Terminal Sensor Subsystems

Fig. 3

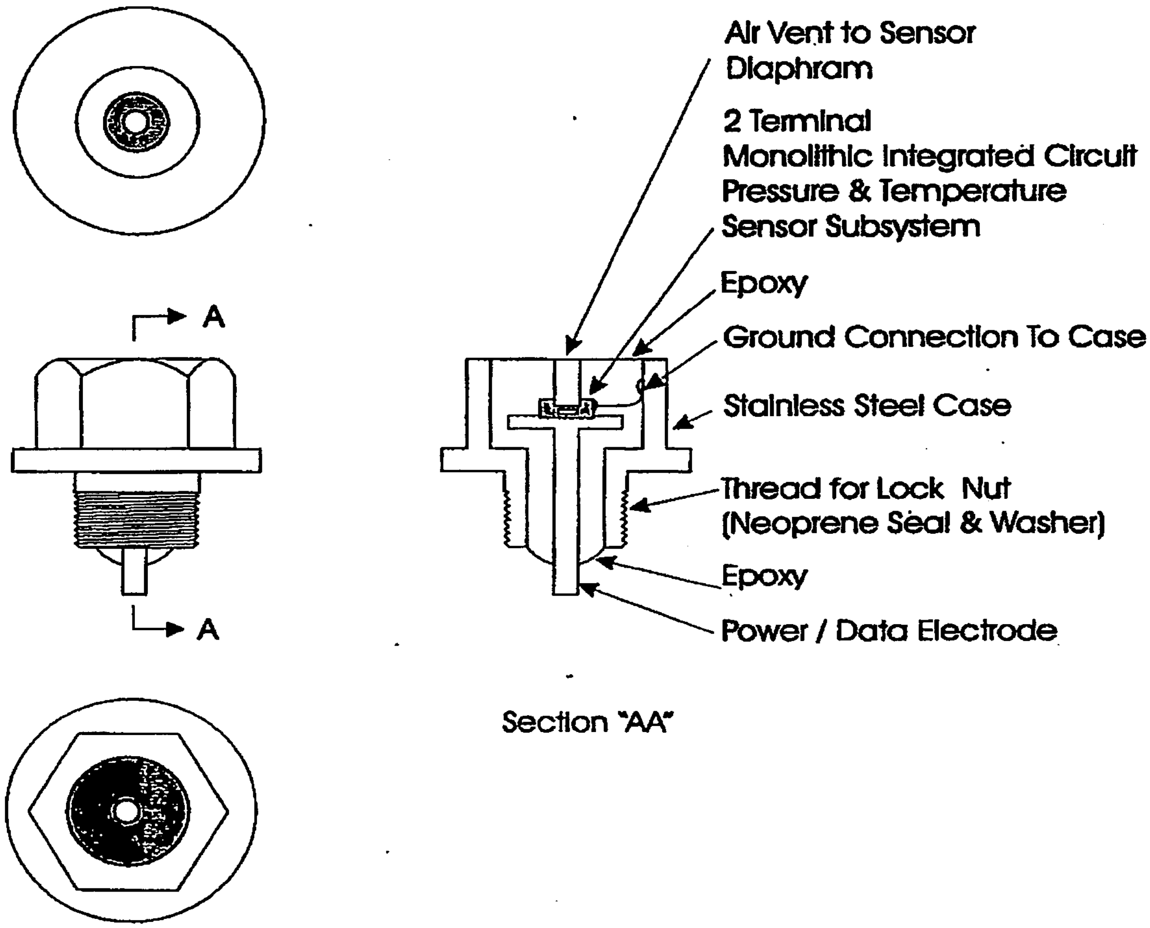


Fig. 4 2 Terminal Sensor Packaging

Not to Scale

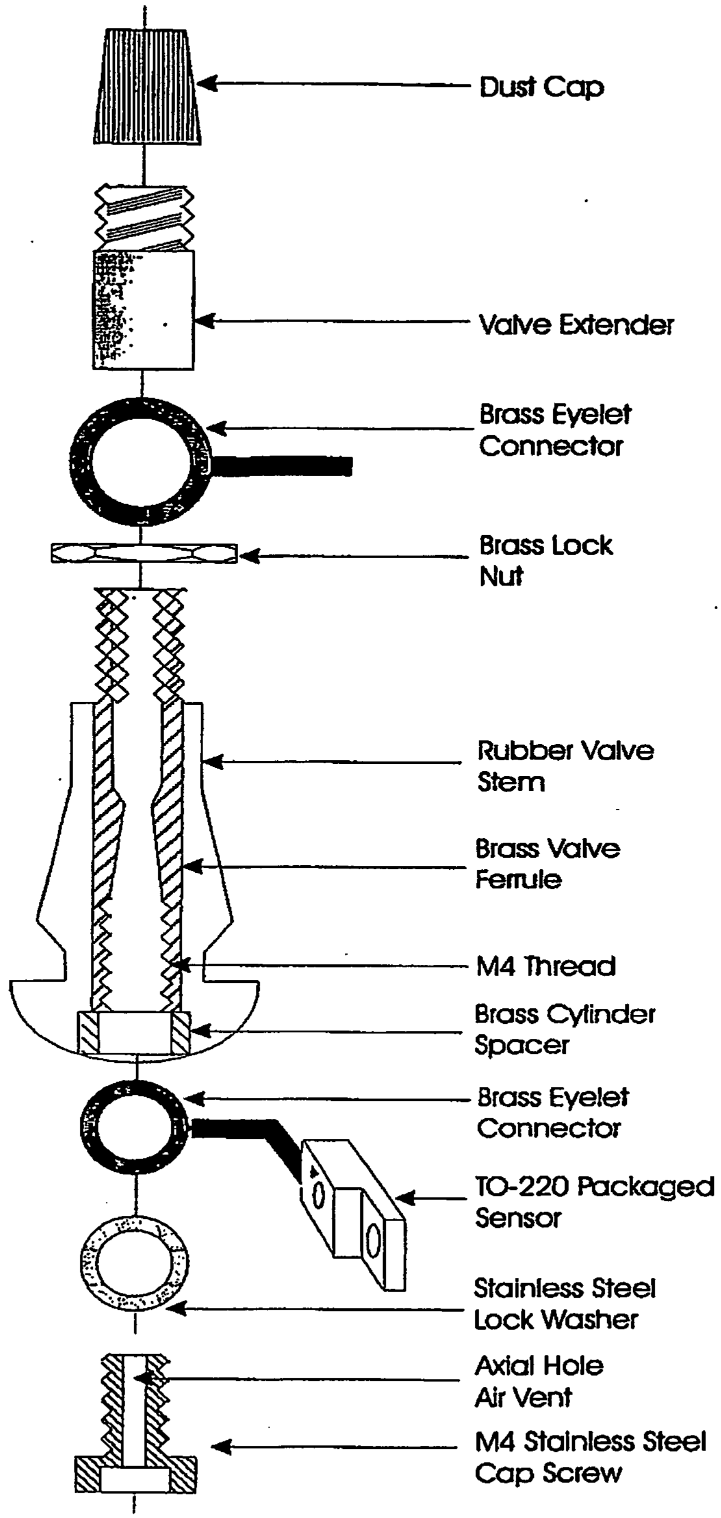


Fig. 5 Tyre Valve Insulated Electrode Used To Connect Sensor To External Face Of Tyre Rim

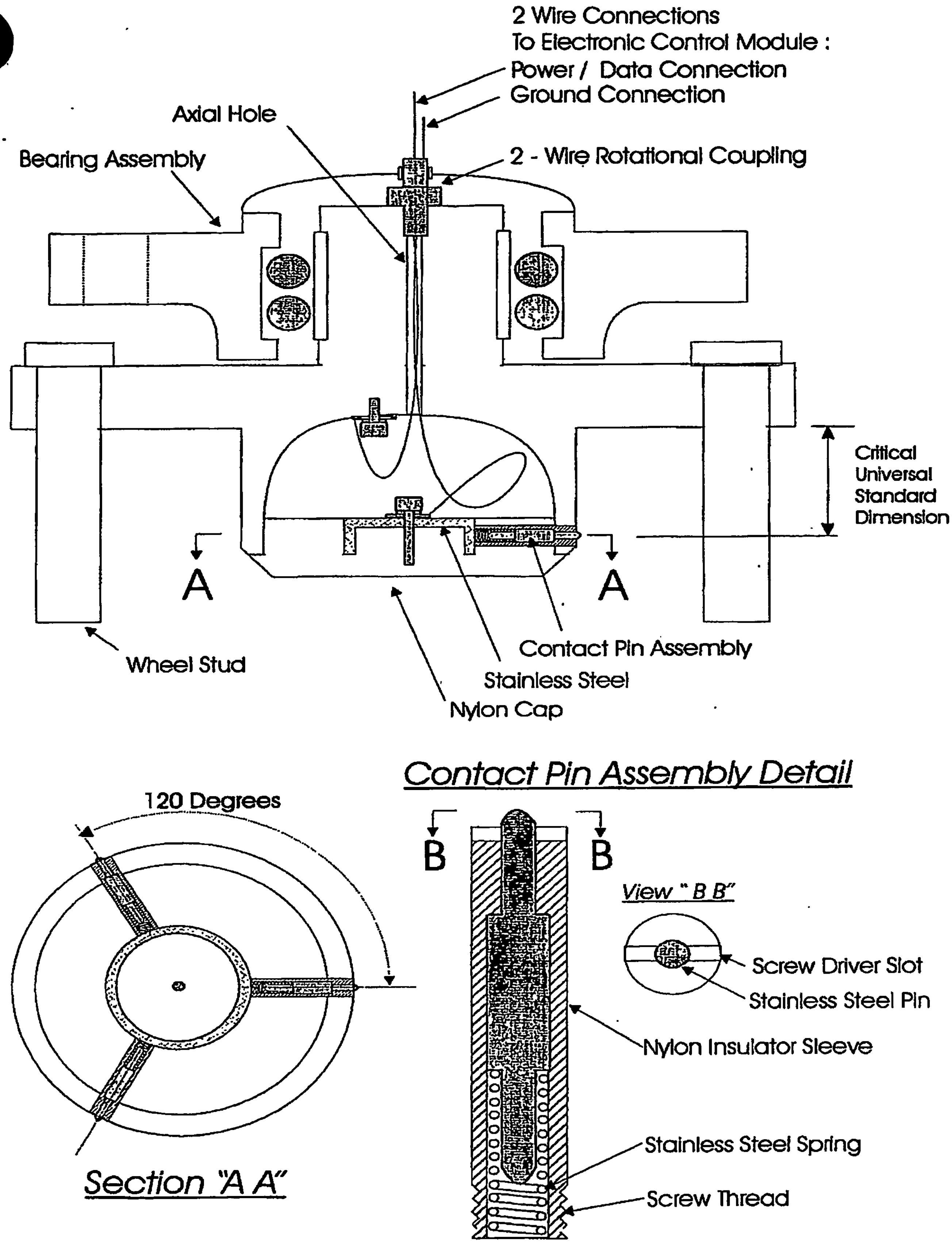


Fig. 6 Wheel Hub Mating System
(Shown On Stub Axle Assembly)

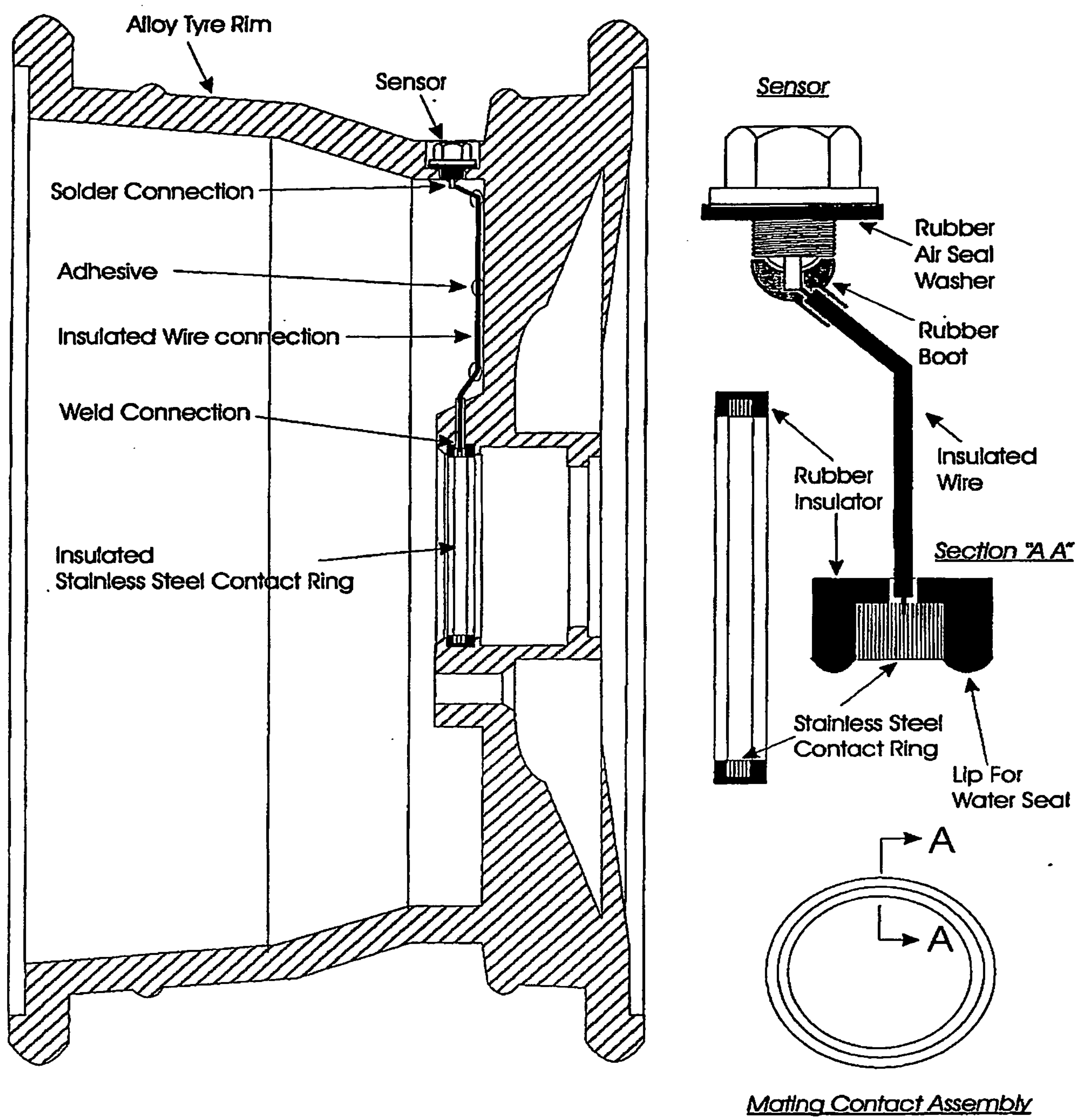


Fig. 7 Alloy Wheel Rim Showing Sensor Mounting And Electrical Connection To Hub Mating Contact Assembly

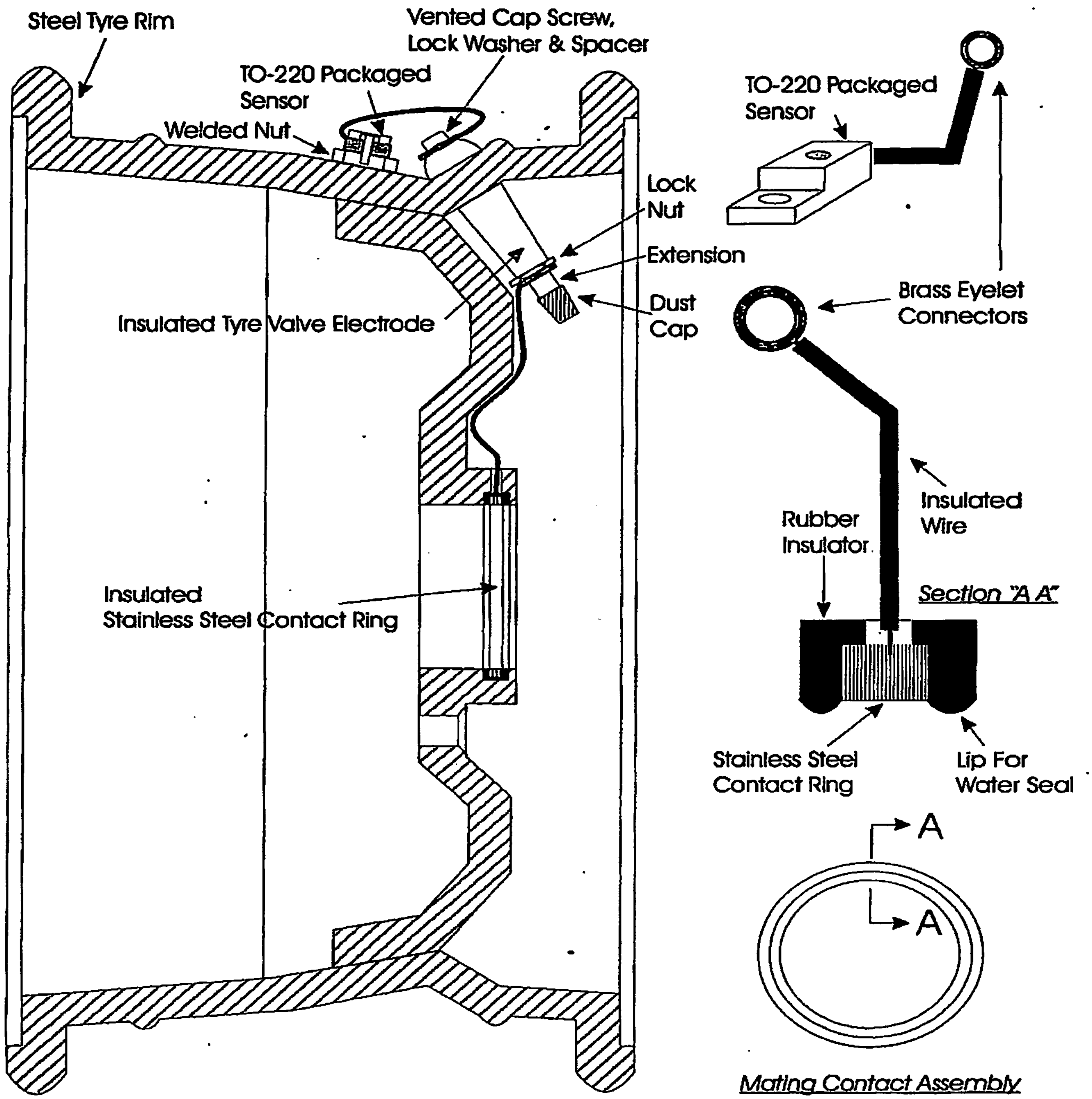


Fig. 8 Steel Wheel Rim Showing Sensor Mounting And Electrical Connection To Hub Mating Contact Assembly

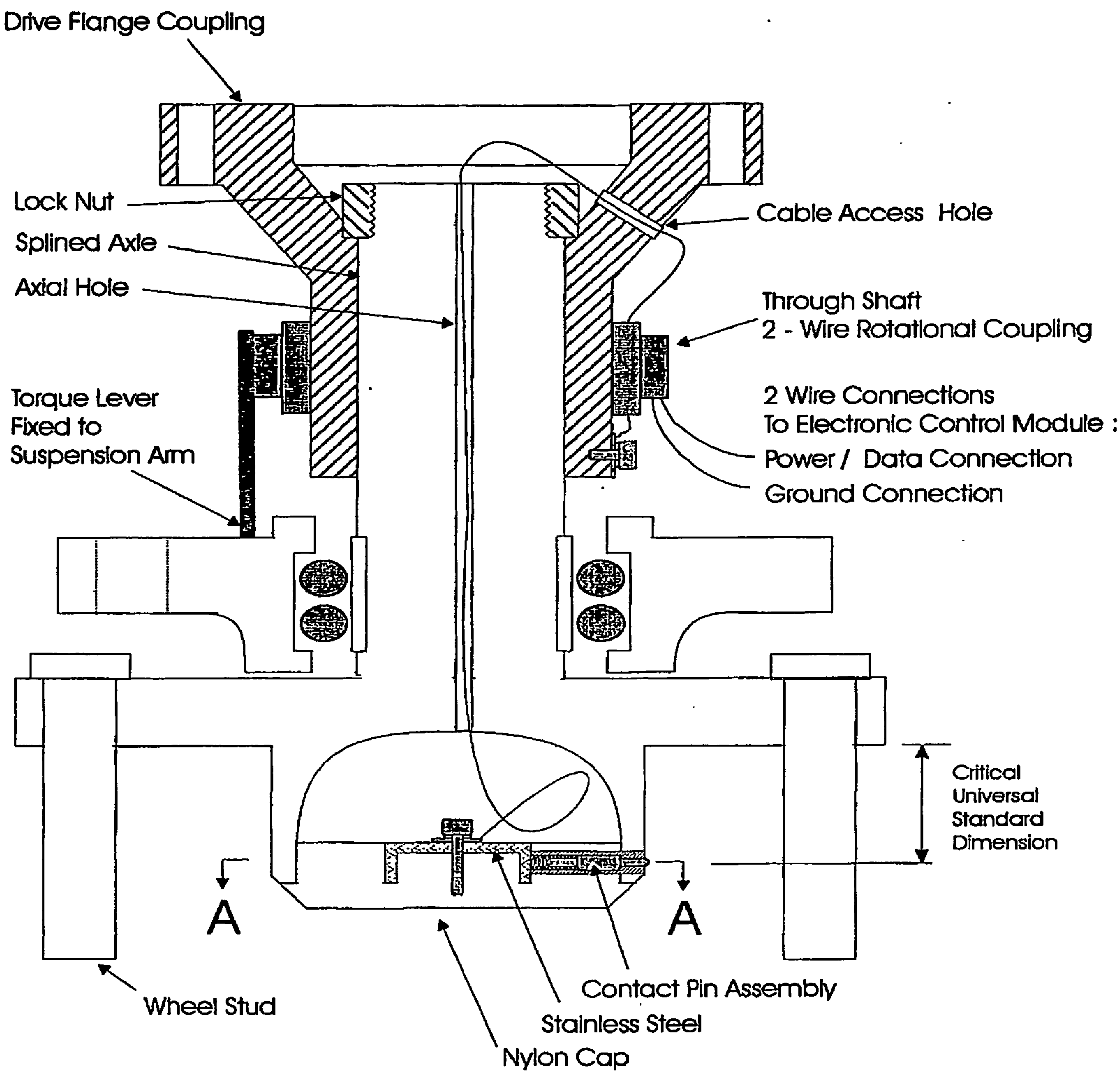


Fig. 9 Wheel Hub Mating Arrangement For Drive Axle

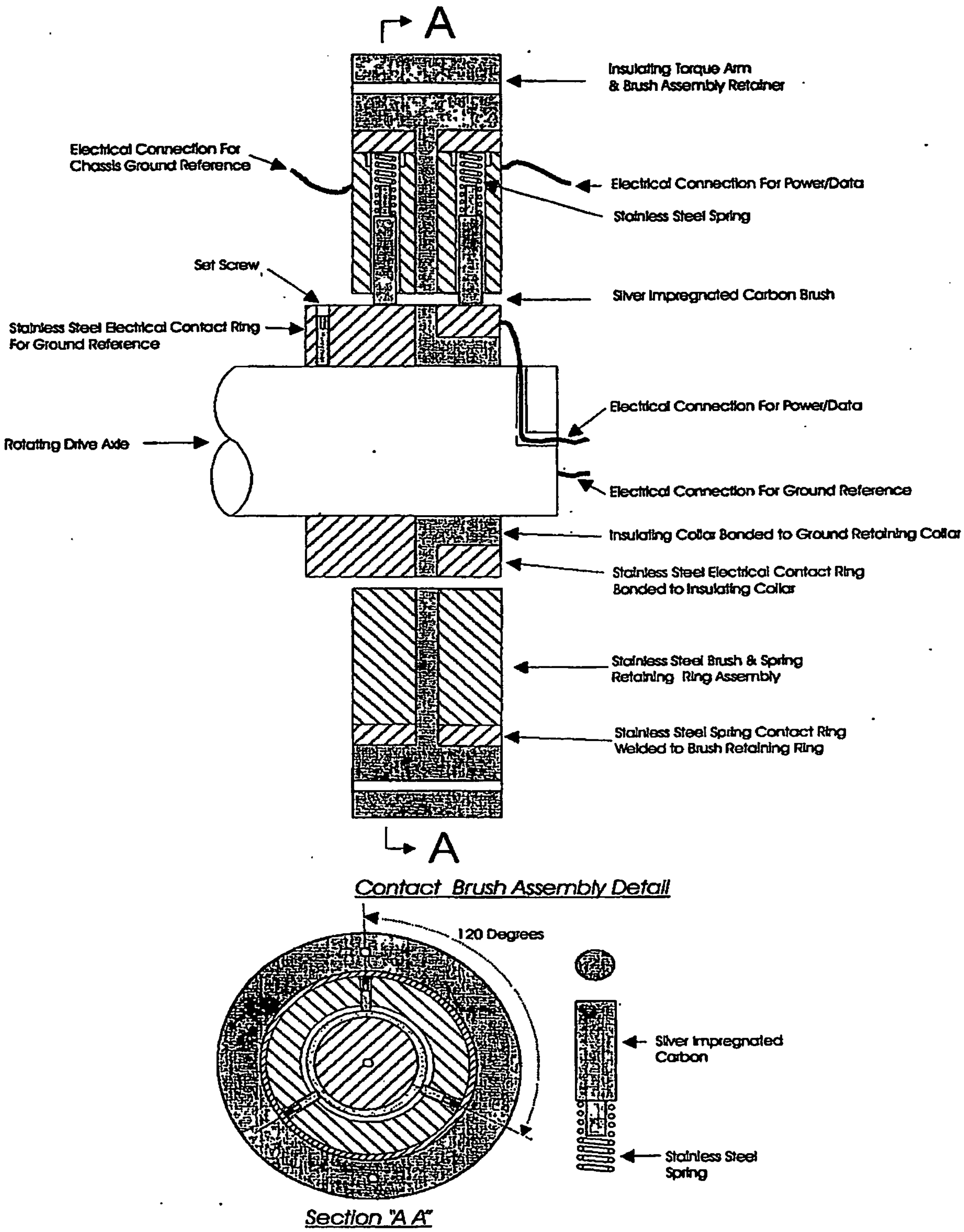


Fig. 10

Through Shaft 2-Wire Rotational Coupling

(Not To Scale)